



Laser Science & Technology

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Laser Drilling of High-Aspect-Ratio, Micron-Scale Holes for NIF Fusion Targets

One of the leading ignition target design for the National Ignition Facility (NIF) requires a capsule with a copper-doped Be ablator. Unlike plastic or glass, this material is impermeable to hydrogen, requiring that a hole be used to fill the capsule with DT fuel. The requirements for this hole are quite stringent because density perturbations in the ablator can enhance Rayleigh-Taylor instability growth during an implosion, which in turn reduces the fusion yield. Recent calculations suggest that a 3- μm -diameter straight hole would probably be acceptable.

Several technologies have been explored in the past for drilling holes of similar dimensions. These techniques include electrical discharge machining (EDM) and ion milling. The main problem encountered in these technologies is a limit in aspect ratio. For instance, EDM is able to drill through the thick material, but only if the hole is opened up to about 8 μm . Conversely, submicron-diameter holes can be made with an ion mill, but only through very thin material.

Under the support of ICF's Target Science and Technologies group, LS&T has recently built a new cutting station (Figure 1) and coupled it to an existing short-pulse

machining laser. The short-pulse laser was selected to minimize the heat deposited in the area surrounding the hole and produce a sufficiently hot plasma such that the ablated material can escape the long, narrow channel.

In order to achieve the desired beam size on the front surface of the material, a high-numerical-aperture (NA) focusing system must be used. The large NA equates to a highly vergent beam into and out of the focal plane, yielding a very short depth of focus ($\approx 1 \mu\text{m}$). Gaussian beam propagation dictates that if the laser were focused to the diffraction-limited spot size on the front surface, the beam diameter at the exit of the capsule would be 135 μm . This is significantly larger than the size of hole required for this application.

A solution to the challenge of beam divergence is presented by the nature of the hole itself. As the hole begins to form, the walls of that hole become a metallic waveguide. This waveguide confines the propagating light in much the same way as an optical fiber.

The hole drilling system utilizes a Ti:sapphire laser that produces 1 mJ per pulse (before compression) at a 3.5-kHz repetition rate. The compressed pulse width is about 110 fs. This pulse is then spatially filtered and frequency doubled to a wavelength of 403 nm. The final available pulse energy is 1 μJ .

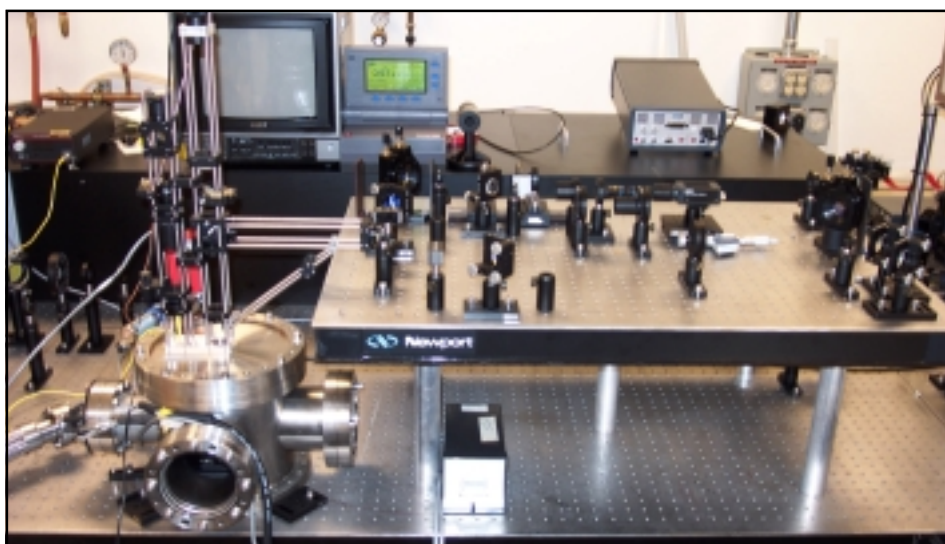


Figure 1. Cutting station for micron-scale hole drilling.

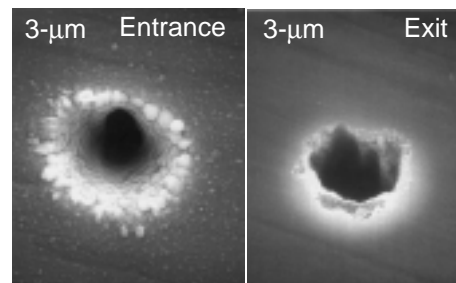


Figure 2. Laser-drilled hole through 125- μm -thick Be foil.

These laser pulses are injected into the collimated space of an infinite-conjugate-ratio microscope. The objective chosen for this project was a single-element aspheric lens with a focal length of 4 mm and a clear aperture of 4.6 mm, yielding an NA of 0.58. Due to the naturally high intensities of short-pulse lasers (about 10^{14} W/cm^2 in this application) and the small focal spot of this system, drilling must be done in vacuum. The lens is housed inside the cutting chamber and is protected from debris by a microscope cover slip.

Since the system was designed with infinite conjugates, the focal plane of the laser and the object plane of the microscope are at the same location. This allows seeing the hole as it is drilled. More importantly, it provides position feedback with sufficient resolution to reproducibly place the target precisely at focus. The microscope itself consists of a fiber-delivered laser illumination source, the aspheric objective and a 40-cm-focal-length tube lens to bring the image created by the objective to the plane of a charge-coupled device (CCD) camera. This microscope provides a field of view of about 75 μm with a resolution of 200 nm per pixel.

Early trials of the system have demonstrated the feasibility of drilling holes that extend more than 100 times beyond the system's Rayleigh range. Three- μm -diameter holes have been drilled in 125- μm -thick Be and Al foils, as well as thin-walled Be capsules. Figure 2 shows the typical entrance and exit of a hole in the Be foil.

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